

GEOLOGIC MAP OF THE HELLAS QUADRANGLE OF MARS

INDEX TO MARINER 9 PICTURES

The mosaic used to control the positioning of features on this map was made with the Mariner 9 A-camera pictures outlined above, identified

by vertical numbers. Also shown (by solid black rectangles) are the

high-resolution B-camera pictures, identified by italic numbers.

surrounding plains) within densely cratered terrain that covers more than half the surface of Mars (Carr, 1973, fig. 1). The deepest part of the basin lies 4-5 km below the surface of the cratered terrain (Hanel and others, 1972). An irregular band of mountain and knobby material about the eastern margin of the basin and broad bands of mantled rough material on the floor of the basin represent ejecta from this very old impact. The vast, gently sloping, featureless eastern and southern part of Hellas Planitia, shown on the Shaded Relief Map of Mars (U.S.G.S., Atlas of Mars, MM 25M IR, 1972), is probably the result of extensive volcanic flooding from shield volcanoes and from possible fissures in the northeast part of the quadrangle. Long, flat-floored sinuous channels originate in these volcanic STRATIGRAPHIC RELATIONS

INTRODUCTION

Crater densities (fig. 1a) indicate that the densely cratered plains material and closely related densely cratered knob and mesa material, together with the mountain and knobby materials, are the oldest map units. In general, densely cratered plains lie in the southeastern part of the quadrangle, densely cratered knob and mesa material and knobby material at lower elevations and successivly closer to the basin. Densely cratered knob and mesa terrain is apparently made up of erosional remnants of easily erodable intercrater areas of densely cratered plains characterized by numerous, randomly oriented sawtooth escarpments. The similar cratering history, random intertonguing, and close spatial relations

The irregular contacts between knobby material and the densely cratered material of the knob and mesa and plains units yield few hints as to relative age. The few isolated patches of mountain and knobby materials within these densely cratered terrains could be tips of ejecta either projecting through or resting upon them. Considered in the context of the origin of the Hellas basin, it is concluded that the Hellas impact occurred during the formation of the densely cratered plains and that this event was preceded and followed by heavy cratering. Hartmann (1973, p. 4105) considered the Hellas impact to post-date heavy cratering. Evidence for Hellas impact predating formation of the densely cratered materials is the presence of a few visible, and perhaps many dust-blanketed craters of intermediate size on the floor of Hellas; the generally patchy nature of the ejecta; absence of obvious secondaries and associated streaks, rays, and related radial features; crater density of ejecta comparable to that of densely cratered plains material and densely cratered knob and mesa material; flat tops of some mountains that may represent an early cycle of erosional planation experienced by densely cratered plains material. Evidence for Hellas impact post-dating densely cratered plains material and densely cratered knob and mesa material is the greater abundance of modified craters in knobby terrain (fig. 2), uggesting infilling of craters in knobby terrain by ejecta; absence of very large craters > 150 km) in knobby terrain; apparent superposition of one mountain mass on rim of large crater, 52° S, 251°. Possibly, the greater abundance of modified craters in knobby and mountain materials relative to densely cratered plains material and densely cratered knob and mesa material (fig. 2) results from more sedimentary and volcanic blanketing in the lower areas near the margin of the basin. Hellas basin was probably formed after the

cratered knob and mesa material, but before the termination of the major stage of planetary The radial pattern of knobby and mountain materials in the east-central part of the addringle may represent partly buried ejecta from a satellitic basin of Hellas, some 600 km in diameter and centered at 45° S. 263° (fig. 3). The major volcanic formations, furrowed shield material, dark mottled plains material, ridged plains material, and peripheral plains material are all younger than the formations considered as evidenced by their lower crater density (fig. 1a). The ridged plains and peripheral plains materials from long embayments into knobby material; randomly scattered mountain peaks, some deeply scoured by erosion, project above peripheral plains and ridged plains materials indicating mountain material to be older than the two volcanic units. Some mountain material may be younger volcanoes. Although the only distinction between the ridged plains and peripheral plains units is lack of recognizable ridges and scarps in the latter, crater characteristics are apparently also different. Peripheral plains nit has a higher percentage of c₁ craters, possibly as a result of greater sedimentary planketing at lower elevation (DAS 7936038, 7936108). Lavas of the ridged plains unit probably flooded from fissures and/or calderas in the northeast corner of the quadrangle, or farther northeast. Lavas of the peripheral plains may have come in part from this source; lavas in the vicinity of 45° S, 260° may have local sources or may have flooded across

The diagnostic lobate pattern of dark mottled plains material against the peripheral plains material east of the northern furrowed shield and a more irregular to sharply lobate pattern (DAS 8621239) against mantled smooth and rough terrains on the floor of Hellas shows the dark mottled plains material to be the younger unit in both areas. The boundary between dark mottled plains and mantled rough materials from 268° to 275° is clearly delineated by the lower albedo of the plains; it is likewise distinguished from peripheral plains from 285° to 289° (DAS 8693269). Spatial relations of dark mottled plains material about the orthern furrowed shield suggest that its lavas came from this source. The northern furrowed shield material clearly embays and floods against mountain terrain west of the shield; its overall tongue shape, elongate downslope, suggests little erosional

modification and a relatively young age. Contact between furrowed shield and dark mottled plains materials appears to be gradational and is drawn at the outer limit of narrow channels and ridges that characterize the shield. The outer limit of the southern furrowed shield is generally vague, but is marked by an apparent slight outward-facing scarp and change in albedo. Contacts between the southern furrowed shield and units to the east Small cratered cones and conical mountains have generally regular outlines and show little The three major channel deposits originate in volcanic terrains and course downslope across volcanic units and mantled rough material. The channel deposits are uncratered except for one 1-km crater on the floor of a tributary to the largest channel and are

The two units on the floor of Hellas, mantled smooth material and mantled rough aterial are very poorly defined because of apparent obscuration by dust in the atmosphere. The subdued nature of their surface suggests a thicker and more pervasive mantle than on other units described under Erosional and Depositional Landforms. Lacking a clear view of the ground surface, it seems likely that craters are more abundant and fresher than indicated on the map. A west-facing curvilinear scarp (DAS 9266849) separates mantled smooth material from mantled rough material, but in general, the contact between the two units is very poorly defined. The most significant feature displayed by the two units is the two broad arcuate bands of mantled rough material that cross the floor of Hellas, together defining a major ejecta blanket (fig. 3); the eastern band is continuous with the Relative age of craters >20 km diameter is determined by crater overlap, by embayment

of some units, such as peripheral plains, into crater floors, and most commonly by degree of degradation of crater rim and inner wall, and level of crater floor. The explanation portrays apparent relative ages of c_1 , c_2 , and c_3 type craters; neither a strict time for the formation of each type nor a correlation with other map units is implied. Crater densities and crater populations for MC-28 (fig. 1a) agree generally with those given by Hartmann (1973, figs. 5, 6), the densely cratered plains in the southeast corresponding to some of his most heavily cratered terrain. Although the separation of craters in MC-28 involves uncertainty because of lack of adequate resolution of rim and inner wall on A-frames and sparse coverage by B-frames, the paucity of fresh (c₃) craters and abundance of older craters (fig. 1b) suggests the dominance of terrain bearing the imprint of a rapidly

Using the pronounced inner topographic boundary along the west edge of the basin as a guide (fig. 3), the inner ring of the basin has a diameter of about 1140 km. Successive theoretical rings, spaced a X 1.4 intervals, coincide with features about the basin: the western band of mantled rough material in MC-28 becomes, with the well-defined high ground outside the quadrangle at about 315°, the first ring. The second ring is unrecognized in MC-28 but its inner boundary corresponds to some linear and arcuate topographic features west and north of the quadrangle. The inner (fault ?) boundary of the third ring lies buried beneath smooth mantled material in MC-28 (Section A-A') but mantled rough material and knobby material together define a broad arcuate band of ejecta whose west edge is inferred to be the eroded and partially buried scarp of this ring. It is significant that at two major lunar basins, Orientale and Imbrium, major ejecta blanke start at the third ring (Wilhelms 1973, p. 4085). The southern furrowed shield in MC-28 is centered at the inner boundary of the third ring and was likely fed by magmas ascending this possible fracture system. The inner boundaries of rings 3, 4, and 5 coincide rather well with annular scarps west and north of MC-28; the inner boundary of ring 4 coincides generally with the inner boundary of an arcuate topographic high shown by Conrath and others (1973, fig. 5). Rings 4 and 5 have no apparent topographic or structural expression

quadrangle (fig. 3) seems best explained as ejecta radially disposed about a possible 600-km Hellas basin, the largest of six basins on Mars (Wilhelms, 1973, p. 4088), has an inner ring diameter more than 1-1/2 times that of Imbrium (675 km), the largest lunar basin. The abundance of ejecta at the east edge of the basin may give an erroneously asymmetrical appearance to the basin's ejecta blanket, for much ejecta probably lies buried beneath younger volcanic terrain in the southern part of the quadrangle. The morphology of the Hellas basin, as shown in the Shaded Relief Map of Mars, is strikingly influenced by volcanic flooding in the eastern and southern parts. Probably the third ring ejecta (fig. 3) served as a dam for volcanic flows coming into the basin from the northeast.

A major northeast-trending fracture system is suggested by a line connecting the two shield volcanoes (fig. 3). This line is parallel to but offset to the west from traces of lines features northeast of MC-28. Another ancient volcanic shield (Tyrrhena Patera) at 22° S, 253° lies on relatively smooth, possibly volcanic, terrain along this trend. In MC-28 the northeast-trending system is further manifest by a chain of volcanic cones and possible calderas at 30° S, 252° and by the parallel courses of the lower reaches of the two major channels near 40° S, 270°. It seems likely that Tyrrhena Patera, the fissure feeders for the ridged and peripheral plains lavas and the two volcanic shields at the margin of Hellas occur along this northeast-trending fracture system, or at the intersection of these fractures with circular fractures related to the Hellas basin.

West-facing irregular escarpments, perhaps 1 km high, can be traced from 61° S. 275° to 48° S. 255° and these are probably highly eroded fault line scarps developed from arcuate aults parallel to the basin rings. North-facing escarpments trending east from 48° S. 240° to 47° S, 255° may be related to the radial disposition of ejecta from the proposed satellitic basin centered at 45° S, 263°. A few high-angle faults, straight scarps assumed to be traces of high-angle faults, and broad-crested ridges in the densely cratered plains, southeastern part of quadrangle, trend northeast and northwest and probably are related to the major fracture system. Wrinkle ridges and curvilinear scarps in the ridged plains unit likewise trend north of northeast roughly parallel to the major system.

Thirty-seven percent of MC-28 is covered by terrain inferred to be of volcanic origin. The most unequivocal large volcanic units are the southern furrowed shield and the northern furrowed shield and related lava field (dark mottled plains). The huge areal extent of these constructs (the southern shield covers more than twice the area of the main construct of Olympus Mons) gives an erroneous impression of their volumes. Topographic determination from infrared spectroscopy (Hanel and others, 1972, fig. 7) shows the southern and northern shields to have very low reliefs, 3-1/2 and 2 km, respectively. Subtracting an assumed pre-volcanic rim elevation of 0.5 km, the southern shield has a maximum thickness of about 3 km, the northern shield, 1-1/2 km. Olympus Mons, by contrast, may have 23 km relief (Carr, 1973, p. 4050). The volume of the southern shield is about 380,000 km³ or about one-fourth that of the main construct of Olympus Mons. Neglecting calculation for possible isostatic compensation, the shields in MC-28 appear to be thin volcanic caps The ridged plains and peripheral plains units, judged by the apparent depth of burial of

mountain peaks, are about 1 km thick and now constitute flat to very gently sloping terrain. Ridges in ridged plains material are interpreted to be broad long extrusions of lava similar to lunar wrinkle ridges on the maria. This evidence, together with great lateral extent, suggests that these two volcanic plains units, as well as the shields, were constructed The small cratered cones and conical mountains occur randomly throughout MC-28 and are superposed on all map units. They are clearly younger than the volcanic shields and ne ridged and peripheral plains units. The most unequivocal small volcanic cone is in the northwest part of the fresh caldera (Barnard) near the summit of the southern shield, 61° S 299° (DAS 6030463, IPL version). Extending from this small cone on the floor of the

FIGURE 2.-Size frequency distribution of craters on stratigraphic units

b. On densely cratered plains material.

a. On knobby and mountain material combined.

c. On densely cratered knob and mesa material.

according to relative crater age

EROSIONAL AND DEPOSITIONAL LANDFORMS Erosional and depositional phases At least three levels of erosion and/or deposition in addition to the floor of the Hellas

basin are apparent in the photographs. The highest (1) is marked by the broad flat intercrater areas in the densely cratered plains, and possibly by the flat to gently sloping summits of mountains at 45° S, 254° (DAS 6174873) and 42° S, 250° (DAS 6174943). A second prominent level (2) is that of the volcanic plains such as the peripheral plains material to which mountain remnants are being eroded. A third, minor, level (3) has been developed by the major channels incised into the volcanic plains units. These three levels are interpreted as follows: Level 1 was produced on the densely cratered plains and Hellas basin ejecta by continued impact, filling of craters, and possibly by eolian and fluvatile erosion. During the long period before major volcanism, level 1 was dissected to an unknown bu apparently great extent segmenting the ejecta blanket. Evidence for widespread fluid erosion at this time is lacking, but clearly some erosion did occur before the latest mantling (see below), for some crater walls are deeply gullied (DAS 9124504, 9124574). Following this phase of erosion, a phase (2) of deposition occurred as lavas (ridged plains, peripheral plains, volcanic shields) flooded the margins of the basin leaving only small remnants of the mountains and knobby materials projecting like icebergs above the lava surfaces. Subsequently, the mountains and other higher remnants were eroded to the level of the lava surface, a stage that appears to be continuing at present. The long sinuous channels (phase 3) are likewise very young and are perhaps still forming. These phases of erosion and deposition cover a very long period of time from the end of planetary accretion to the present and were probably intermittent rather than continuous processes (Milton 1973, p.

Eolian Landforms With the exception of certain surface features and map units noted below, most landforms in MC-28 have a smooth, rounded appearance at B-frame resolution, generally not apparent in A-frames. The subdued character of the surface forms is apparently part of a planet-wide mantling by eolian debris poleward from 30° S and 30° N latitudes (Soderblom and others, 1973); the maximum thickness of the mantle is estimated to be between 100 m and 1 km. The dark mottled plains, northern furrowed shield, and parts of the ridged plains units appear to be almost unmantled near the northern edge of the mantling blanket. Mountain peaks and conical mountains appear to have escaped mantling, possibly owing to high relief and steep slopes; some small cratered cones and related lava flows appear unmantled and these may be very young or contemporaneous with the mantling. Certain parts of the peripheral plains unit appear to have no mantle, possibly because strong basinward winds have swept some of this terrain clean. In addition to this rather pervasive mantling, there is limited evidence in the area of quadrangle MC-28 for contemporaneous or younger transport and deposition by wind

ig. 4). Dark fields, patches, and streaks are common in the densely cratered plains utheast) and along ridges on the floor of Hellas, possibly most abundant near or downslope from volcanic terrains. The most common evidence for direction of transport is the dark (lag?) streaks and patches in the apparent lee of crater rims. Similarly, crescent-shaped accumulations of dark material on the up-wind side of large crater floors may be lag in a turbulent zone. Longitudinal dunes, thinly mantled, occur at four sites in the quadrangle. In the northeast corner of MC-28 are the only light crater plumes—long, broad, light streaks in the lee of craters, oriented 180° from dark streaks in the same general area. The light streaks probably result from the major 1971 dust strom. Wind directions inferred from ark markings and dunes accord generally with those given by Sagan (Sagan and others, The only evidence suggesting significant wind erosion in MC-28 is the serrated edges of some escarpments in the intercrater areas in the densely cratered plains and the grainy appearance of some of the knob and mesa material. Good photographic resolution of these

features is lacking. Fluid erosion and mass wasting

Mountain remnants rising boldly above the peripheral plains show evidence of mass wasting (DAS 9052054, 9052124). Mountain crests are reduced to sharp ridges with multiple branching spurs. Upper, very steep slopes have many long narrow tongues of debris that terminate at the base of the steepest slopes or on gentle, slopes at the mountain base. About these gentler slopes is a smooth apron, 5-51 km wide, that slopes very gently away from the mountain base; the outer margin is broadly lobate. All these forms are attributed to mass wasting: the narrow tongues on steep slopes may have been produced by rapid downslope movement of coarse debris; the broad peripheral apron, by some form of slow creep, perhaps aided by melting of finer materials derived from the mountain base. Three major channels extend into the Hellas basin. The largest, denoted A in this discussion, more than 1500 km long, starts at 37° S, 247° and terminates at 43° S, 275°, as well shown in four B-frames (DAS 8908624, 8908834, 8908764, 8908694). Channel B, 600 km long, starts at 35° S, 267° and terminates at 40° S, 277°. Channel C (DAS 7935763), about 400 km long, starts at 61° S, 286° and terminates at 55° S, 285°. All three channels originate in and traverse volcanic units to the margin of the Hellas basin. Channel B starts in a conspicuous steep-walled amphitheater in the vicinity of numerous collapse depressions at the east base of the northern shield. The head of channel B is faint and shallow, that of C narrow and deep. Channels A and B have a rather constant width of 10-20 km throughout their extent, whereas C widens downstream, then becomes narrower near its terminus. Arcuate bays and broad featureless reaches, where little or no channel is seen, typify A. One such broad featureless reach in B is followed down-channel by two narrow, deep, rounded channel depressions resembling plunge pools. Channels A and B appear to terminate without significant depositional form in large arcuate or circular rough-floored pits, probably craters, but photographic resolution is poor and both channels may course farther toward the center of the basin. The terminus of channel C is poorly defined. Channel walls are steep; floors are flat and show some faint structures parallel to the channel walls. Some islands on the channel floors are sharpened upstream, some downstream. Channel courses are straight to broadly sinuous except where modified by conus mass wasting. On A-frames, tributaries are seen to be sparingly developed. B-frames, the few larger tributaries (1 km wide) suggest morphologies similar to that of the main channels; the smaller tributaries are narrow rilles incised into the blanketing mantl and other units and commonly dendritic (DAS 9052054). Direction of flow is shown by bank undercutting and preservation of terraces on the opposite bank, and by acute junction of tributaries. Evidence of slumping and other mass wasting includes long, breakaway slump scarps on upland near channel walls; irregular slumped masses on channel floors; narrow chutes or grooves on steep channel walls; and semicircular slump pits, 1-2 km, across, some with a downslope rempart, and arrayed at two levels along the side of the channel (DAS 9052054). In addition to the larger channels and their tributaries, many smaller channels or rilles are

seen on both A and B frames. Most are near the margin of Hellas Basin, mainly, though not entirely, restricted to the volcanic terrains. Several small channels start and/or terminate The sum of this evidence suggests erosion of major and minor channels by fluids, most likely water that originated in volcanic terrains, possibly through local melting of permafrost in the areas of higher than normal heat flow, possibly from fumaroles. The channels have the characteristics of voluminous, short-lived flow. Possibly the fluids cut and melted frozen ground as they flowed, producing the arcuate embayments; broad featureless regions developed where they spread thin or volatilized, and deep plungepool-like pits formed where local deep melting or corrasion occurred. Mass wasting may have been accelerated by subsequent melting at various levels in the channel walls. The semicircular slump pits suggest sapping due to such melting. Poor definition of the terminii of three major channels in the photographs may be due to dust obscuration, or water may have left the channels by olatization, escaping into the thin atmosphere. Channel cutting is a relatively recent event in the area covered by MC-28. The channels are morphologically young, being only slightly blanketed by the recent pervasive planetwide mantle, and are almost uncratered. Their formation probably post-dated major volcanism by a long period of time.

SUMMARY OF GEOLOGIC HISTORY Intensive cratering during the late stages of accretion of Mars was punctuated by the impact of a major bolide that formed the Hellas basin with five rings. A smaller satellitic basin may have formed at this time. Subsequent cratering, and possibly fluid and eolian erosion, subdued the rings and ejecta blanket. Much later, in the late stages of cratering of the planet, there was a voluminous outpouring of fluid lavas that formed two large volcanic shields on the margin of the basin and large lava fields, burying much of the original land surface about the eastern and southern part of the basin. The eruptions apparently occurred along a major northeast-trending fracture system and at the intersection of this system with circular fractures of the Hellas basin. As impact cratering decreased, eolian deposits blanketed much of the terrain and small volcanic cones formed across the quadrangle. Finally, fluids, possibly derived from melting of permafrost in volcanic terrains, or from fumaroles, cut and melted three major and numerous smaller channels that course across the volcanic terrain toward the center of the basin. REFERENCES

Carr, M. H., 1973, Volcanism on Mars: Jour. Geophy. Research, v. 78, no. 20, p. 4049-Carr, M. H., Masursky, Harold, and Saunders, R. S., 1973, A generalized geologic map of Mars: Jour. Geophys. Research, v. 78, no. 20, p. 4031-4036. Conrath, B. J., Curran, R. K., Hanel, R. A., Kunde, V. G., Maguire, W. W., Pearl, J. C., Pirraglia, J. A., Welker, J. R., and Burke, T., 1973, Atmospheric and surface properties of Mars obtained by infrared spectroscopy on Mariner 9: Jour. Geophys. Research, v. 78, no. 20, p. 4267-4278. Hanel, R. A., Conrath, B. J., Hovis, W. A., Kunde, V. G., Lowman, P. D., Jr., Maguire, W. W., Pearl, J. C., Pirraglia, J., A., Prabhakara, C. Schlachman, B., Levin, G., Straat, P. A., and Burke, T., 1972, Investigation of the Martian environment by infrared spectroscopy on Mariner 9: Icarus, v. 17, no. 2, p. 423-442. Hartmann, W. K., 1973, Martian cratering, 4, Mariner 9 initial analysis of cratering chronology: Jour. Geophys. Research, v. 78, no. 20, p. 4096-4116. Milton, D. J., 1973, Water and processes of degradation in the Martian landscape: Jour. Geophys. Research, v. 78, no. 20, p. 4037-4047. Sagan, Carl, Veverka, Joseph, Fox, P., Dubisch, Roy, French, R., Gierasch, P. J., Quam, L. O., Lederberg, Joshua, Levinthal, E. C., Tucker, R., Eross, B., and Pollack, J. B., 1973, Variable features on Mars, 2, Mariner 9 global results: Jour. Geophys. Research, v. 78, no. 20, p. 4163-4196. Soderblom, L. A., Kreidler, T. J., and Masursky, Harold, 1973, The latitudional distribution of a debris mantle on the Martian surface: Jour. Geophys. Research, v. 78, no. 20, p. Wilhelms, D. E., 1973, Comparison of Martian and lunar multiringed circular basins: Jour.

Geophys. Research, v. 78, no. 20, p. 4084-4095.

Crater

Caldera

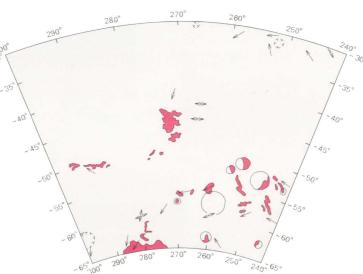
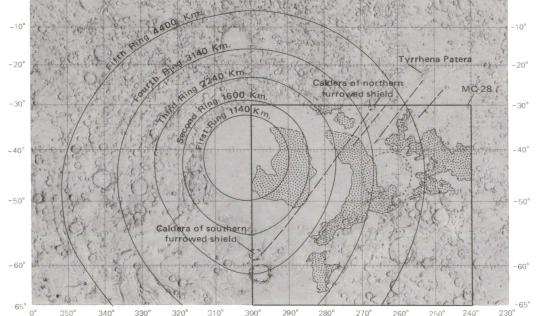


FIGURE 4.-Major dark areas assumed to be of eolian deposition and/or deflation, are shown in red. EXPLANATION Wind direction, inferred from dark streaks and brushes --- Broad, light crater plume Trend where wind direction uncertain



350° 340° 330° 320° 310° 300° 290° 280° 270° 260° 250° 240°

FIGURE 3.-Proposed rings of Hellas basin. Diameter of successive rings is 1.4 times diameter of next innerring. Dotted circle, proposed satellitic impact crater of Hellas. Stippled pattern, proposed ejecta blanket; dashed lines, major fracture system.